THE MAGNETOSPHERIC CUT-OFF FOR 1.5 MEV EXTRA-TERRESTRIAL PROTONS

C. Y. Fan, J. A. Simpson and Edward C. Stone

THE UNIVERSITY OF CHICAGO

THE ENRICO FERMI INSTITUTE FOR NUCLEAR STUDIES

0 5 9 1032

Chicago U., Ill.

(2) Enrico Fermi Inst. for Nuclear Studies

(NASA CR-53180; EFINS-64-5)

THE MAGNETOSPHERIC CUT-OFF FOR 1.5 MEV EXTRA-TERRESTRIAL PROTONS‡

C. Y. Fan§,
Laboratories for Applied Sciences and Enrico Fermi Institute for Nuclear Studies

and

J. A. Simpson, and Edward C. Stone*
Enrico Fermi Institute for Nuclear Studies
and Department of Physics
University of Chicago
Chicago 37, Illinois

OTS: $1.10 ph, $0.80 mf

12 NOTS

Submitted to:

Physical Review Letters

February 1964 9 p refs Submitted for Publication

‡ This research was supported in part by the Air Force Geophysical Research Directorate under Contract AF 19 (628)-2473, by the Air Force Office of Scientific Research under Grant AF-AFOSR-62-23, and by the National Aeronautics and Space Administration under Grant No. NASA-NsG-179-61 Res.

* Now at California Institute of Technology, Pasadena, California

(NASA Grant NsG-179-61; Contract AF 19(628)-2473; AF AFOSR Grant 62-23)

Index: AF-AFOSR-62-33

THE MAGNETOSPHERIC CUT-OFF FOR 1.5 MEV EXTRA-TERRESTRIAL PROTONS‡

C. Y. Fan
Laboratories for Applied Sciences and Enrico Fermi Institute for Nuclear Studies

and
J. A. Simpson and Edward C. Stone*
Enrico Fermi Institute for Nuclear Studies
and Department of Physics
University of Chicago
Chicago 37, Illinois

A study over the geomagnetic polar regions of the arrival of extraterrestrial low energy protons during a period of low geomagnetic activity is important both for a physical description of the distant magnetosphere and for understanding the ionization of the upper atmosphere over the polar regions by solar flare protons. Investigations below ~ 20 MeV have been possible only recently with detectors on polar orbiting satellites. Pieper, et. al.,[1] and Zmuda, et. al.,[2] reported some results obtained prior to the sudden commencement (SC) of magnetic storms. During the pre-SC observations, proton fluxes greater than 200 cm^{-2} sec^{-1} sr^{-1}, integrated over the 1.5 to 15 MeV energy interval, were measured up to ~ 78° geomagnetic latitude. They found these protons arriving down to ~ 65° geomagnetic latitude. However, the wide energy interval and the lack of a sharp cut-off made the interpretation of this threshold latitude difficult.

We report here some results from an oriented satellite whose orbit passed over the geomagnetic pole carrying detectors sensitive to 1.5 MeV protons from both the vertical and horizontal directions and insensitive to electrons. On 19 September 1961 the 1.5 MeV proton flux was of order 10 cm^{-2} sec^{-1} sr^{-1}, far below the flux levels

where collective particle motions could be important. It is shown that protons of approximately 2 Mev arrive with full intensity down to a geomagnetic latitude of 65°, whereas Stoermer theory predicts their cut-off at approximately 75°. Since it has been generally assumed that protons of 50 Mev (Stoermer cut-off) and in no case less than 15 Mev, represented the lowest energy protons arriving down to 65° from interplanetary space during undisturbed periods of the geomagnetic field, these results clearly indicate the importance of re-examining present models of the geomagnetic cut-off mechanism and point to a revision in the energy range of solar flare protons associated with cosmic radio noise absorption.

The basic instrument was a telescope composed of two Au-Si surface barrier detectors, one behind the other. An aluminum collimator defined an acceptance cone with a half-angle of 65°. Details of the telescope design have been published.[3] One telescope (V) was oriented in the vertical direction, with another telescope (H) in the horizontal direction as shown in Fig. 1. The count rates presented here will be those of the front detector of the V-telescope (1.4 - 4.4 MeV) and the front detector of the H-telescope (1.1 - 6 MeV). This instrument was carried by Discoverer XXXI into a low altitude (300 kilometer) polar orbit on 17 September, 1961. Data from many north and south polar passes have been studied. Figure 2 shows data from 19 September 1961 which were selected as an example to show the special case of consecutive passes almost directly over the north and south poles. There is an abrupt transition between the low latitude background (mostly alpha particle events from uranium used to check instrument performance) and the solar proton flux, which is essentially constant over the entire polar region. This indicates they could not be trapped protons. In addition, the count rates of the V- and H-telescopes, when adjusted for the different

thresholds and for the geometrical correction to account for allowed pitch angles, are consistent with a flux isotropic over the upper hemisphere. Note that the transition in counting rate is more abrupt for the side away from the sun direction (dark side) than for the sun side. The latitude to reach full intensity is $\sim 5^{\circ}$ higher on the sun-side. The vertical and horizontal transition latitudes are quite similar. These results are typical of all polar passes. This proton flux was simultaneously detected > 10 earth radii (R_e) by Bryant et. al.[4] in Explorer XII. Thus, it is almost certain that the protons were of solar flare origin.

The count rate data from the rear detectors of both telescopes (6 - 8 Mev) indicates a differential energy spectrum of $\sim E^{-2.5}$, so that the front detector count rate is to be assigned to the lowest detectable energy, namely 1.5 Mev. Cahill[5] found that the geomagnetic cavity was undisturbed at this time out to more than 12 R_e. Since the lines of magnetic force at 65° cross the equator at less than this distance these results are for a relatively undisturbed geomagnetic field. Therefore, the observed cut-off energy of 1.5 Mev at $\sim 65^{\circ}$ is to be compared with the expected proton cut-off energy of at least 15 Mev. This discrepancy, and the diffuse cut-off on the sun-side, are likely to arise from the interaction of the solar wind with the magnetosphere. The local time dependence of these non-Stoermer cut-off latitudes and their significance for a geomagnetic cut-off theory have been investigated by Stone[6] using the data from more than 30 polar traversals.

The authors are indebted to the Laboratories for Applied Sciences for the construction of the instrumentation, and to Dr. A. Tuzzolino and Mr. M. Perkins for the preparation of the gold-silicon detectors. The difficult data reduction was carried out by the Enrico Fermi Institute cosmic ray group. The authors were

especially grateful to Dr. L.Katz and Mr. D. Smart of the Cambridge Geophysical Research Directorate, and to the Livermore Laboratory staff for the flight arrangements and for assigning data channels on the inflight tape recorder to our experiment. One of us (E.C.S.) thanks the National Aeronautics and Space Administration for a fellowship during part of this investigation.

---

‡ This research was supported in part by the Air Force Geophysical Research Directorate under Contract AF 19 (628)-2473, by the Air Force Office of Scientific Research under Grant AF-AFOSR-62-23, and by the National Aeronautics and Space Administration under Grant No. NASA-NsG-179-61 Res.

* Now at California Institute of Technology, Pasadena, California.

1. G. F. Pieper, A. J. Zmuda and C. O. Bostrom, J. Geophys. Res. 67, 4959 (1962).

2. A. J. Zmuda, G. F. Pieper and C. O. Bostrom, J. Geophys. Res. 68, 1160 (1963).

3. R. Takaki, M. Perkins, and A. Tuzzolino, I.R.E. Trans. on Nuc. Sci. NS-8, 64 (1961).

4. D. A. Bryant, T. L. Cline, V. D. Desai and F. B. McDonald, Phys. Rev. Letters 11, 144 (1963).

5. L. J. Cahill, private communication (1963).

6. E. C. Stone, to be published.

FIGURES

Figure 1. Cross-section view perpendicular to the vehicle velocity axis, oriented as shown with respect to the earth. The view angles of the two solid-state detector telescopes are shown.

Figure 2. Proton counting rates are shown for two consecutive polar passes and for both the vertical (V) and the horizontal (H) directions. The counting rate errors are $\pm$ 12 percent.

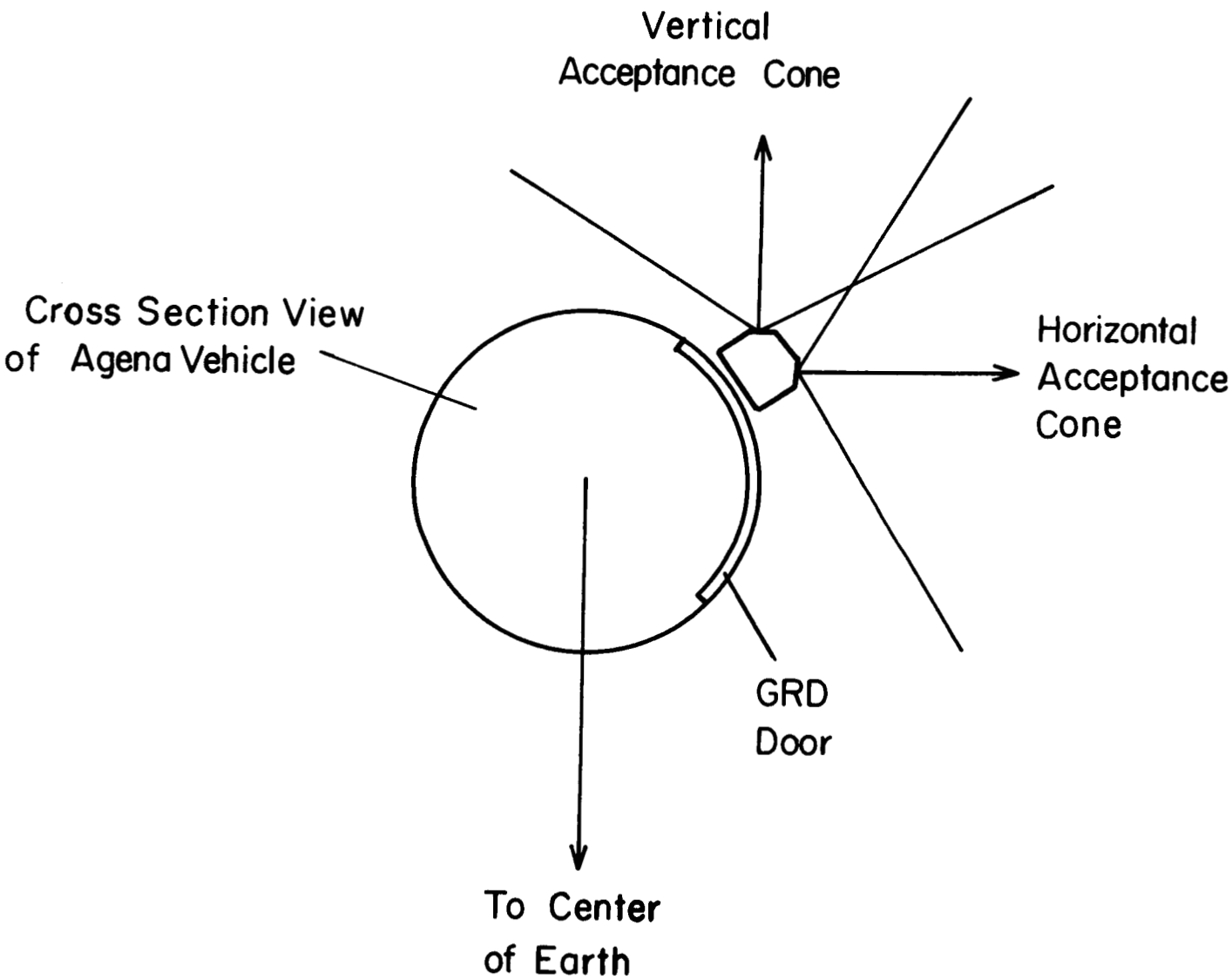
Vertical
Acceptance Cone
Cross Section View
of Agena Vehicle
Horizontal
Acceptance
Cone
GRD
Door
To Center
of Earth

Fig.I

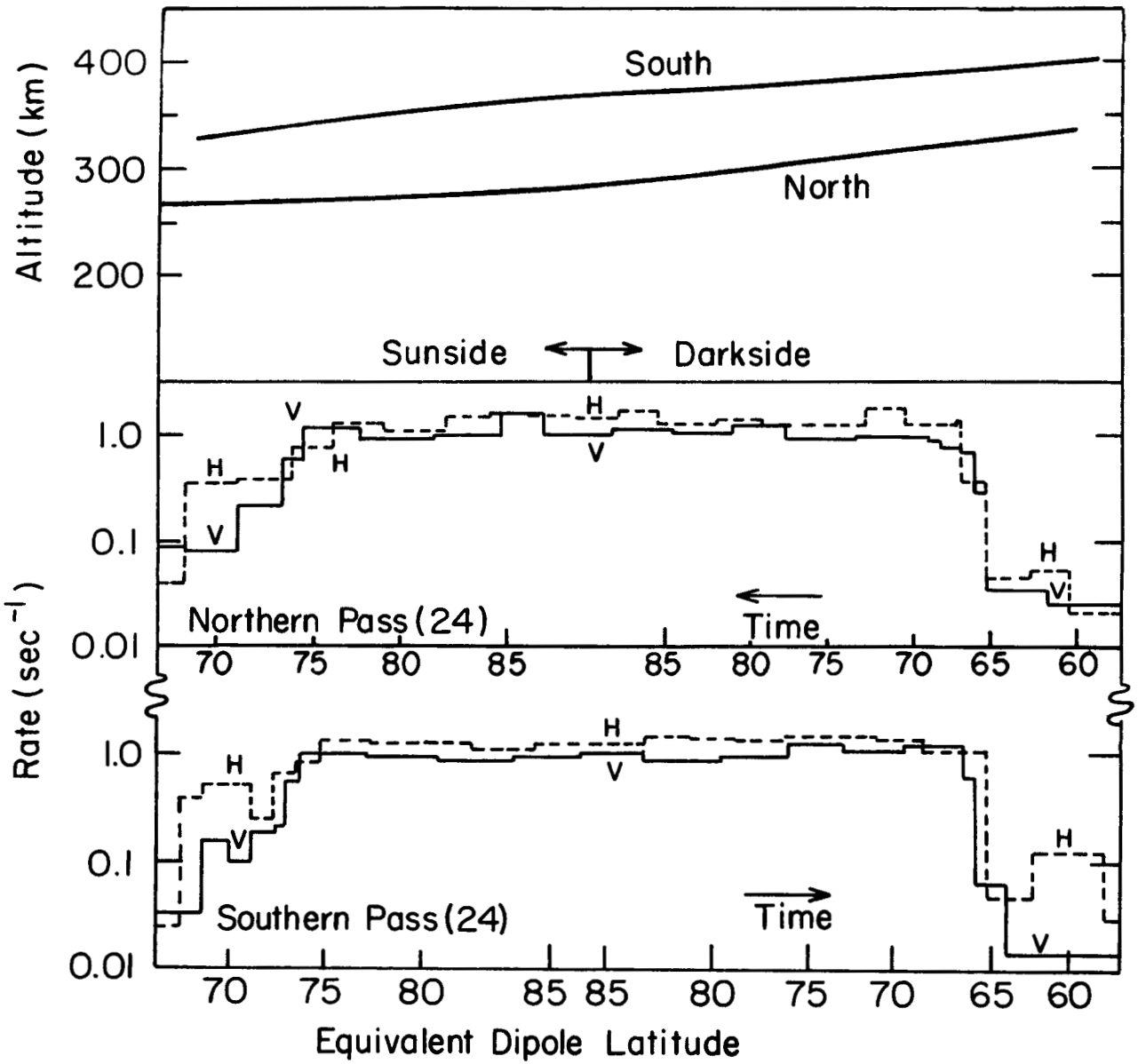
Altitude (km)
400
300
200
South
North
Sunside
Darkside
Rate (sec⁻¹)
1.0
0.1
0.01
V
H
Northern Pass (24)
Time
70 75 80 85 85 80 75 70 65 60
Southern Pass (24)
Time
70 75 80 85 85 80 75 70 65 60
Equivalent Dipole Latitude

Fig. 2